Enhanced Higgs-Mediated Lepton-Flavour-Violating Processes in the Supersymmetric Inverse Seesaw Model

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Summary. — We study the impact of the inverse seesaw mechanism on several leptonic and hadronic low-energy flavour-violating observables in the context of the Minimal Supersymmetric Standard Model. Indeed, the contributions of the light right-handed sneutrinos from the inverse seesaw significantly enhance the Higgs-mediated penguin diagrams. We find that this can increase the different branching ratios by as much as two orders of magnitude.

1. – Introduction

Being highly suppressed in the Standard Model (SM), any charged lepton-flavour-violating (cLFV) signal would be a clear evidence of new physics: mixings in the lepton sector and probably the presence of new particles, possibly shedding light on the origin of neutrino mass generation. Among the extensions of the SM, supersymmetry (SUSY) is a well-motivated solution for the hierarchy problem, providing also gauge couplings unification and dark matter candidates. However, the minimal supersymmetric extension of the SM (MSSM) does not provide a mechanism to generate neutrino masses, which can be done by embedding a seesaw mechanism in the MSSM. The inverse seesaw [1] is a very appealing choice since it provides large neutrino Yukawa couplings ($Y_\nu \sim O(1)$) and a seesaw scale close to the electroweak one, thus within LHC reach.

2. – Supersymmetric Inverse Seesaw and Higgs-Mediated LFV

The SUSY inverse seesaw model consists of the MSSM extended by three pairs of singlet superfields, $\widehat{\nu}_i^c$ and $\widehat{X}_i$ ($i = 1, 2, 3$), with opposite lepton numbers, and is defined by the superpotential

$$\mathcal{W} = \varepsilon_{ab} \left[Y_d^{ij} \widehat{D}_i \widehat{Q}_j^b \widehat{H}_d^a + Y_u^{ij} \widehat{U}_i \widehat{Q}_j^a \widehat{H}_u^b + Y_e^{ij} \widehat{E}_i \widehat{L}_j^b \widehat{H}_d^a + Y_\nu^{ij} \widehat{\nu}_i^c \widehat{L}_j^a \widehat{H}_u^b - \mu \widehat{H}_d^a \widehat{H}_u^b \right]$$

$$+ M_{R_i} \widehat{\nu}_i^c \widehat{X}_i + \frac{1}{2} \mu_{X_i} \widehat{X}_i \widehat{X}_i \,, \tag{1}$$

where $i, j = 1, 2, 3$ denote generation indices. In the above, $\widehat{H}_d$ and $\widehat{H}_u$ are the down- and up-type Higgs superfields, $\widehat{L}_i$ denotes the SU(2) doublet lepton superfields. M_{R_i} represents the right-handed (RH) neutrino mass term which conserves lepton number while μ_{X_i} violates it. More details are given in [2]. In this model, the smallness of the left-handed neutrino mass is due to the smallness of μ_{X_i}, thus leaving the mass parameters $m_D = Y_\nu v_u$ and M_R unconstrained. The only source of flavour violation is encoded in the neutrino Yukawa couplings Y_ν. Even under the assumption of universal soft breaking terms at the GUT scale, radiative effects will induce flavour violation in the slepton mass matrices, which in turn gives rise to slepton-mediated cLFV [3]. As an example, the RGE corrections to the left-handed slepton soft-breaking masses are given by

$$(\Delta m_{\widetilde{L}}^2)_{ij} \simeq -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger L Y_\nu)_{ij} = \xi (Y_\nu^\dagger Y_\nu)_{ij} \,, \quad L = \ln \frac{M_{GUT}}{M_R} \,. \tag{2}$$

Compared to the type I seesaw, where $M_R \sim 10^{14}$ GeV, the inverse seesaw has a RH neutrino mass scale $M_R \sim \mathcal{O}(\text{TeV})$ and this leads to an enhancement of the factor ξ and hence to all low-energy cLFV observables. Furthermore, having RH sneutrinos with a mass $M_{\widetilde{\nu}^c}^2 \sim M_{\text{SUSY}}^2$, the $\widetilde{\nu}^c$-mediated processes are no longer suppressed, and might even significantly contribute to the low-energy LFV observables through the new diagram given in fig. 1. Notice that in the type I SUSY seesaw, this contribution is usually neglected.

The effective Lagrangian describing the couplings of the neutral Higgs fields to the charged leptons being given by [4]

$$-\mathcal{L}^{\text{eff}} = \bar{E}_R^i Y_e^{ii} \left[\delta_{ij} H_d^0 + \left(\epsilon_1 \delta_{ij} + \epsilon_{2ij} (Y_\nu^\dagger Y_\nu)_{ij} \right) H_u^{0*} \right] E_L^j + \text{h.c.} \,, \tag{3}$$

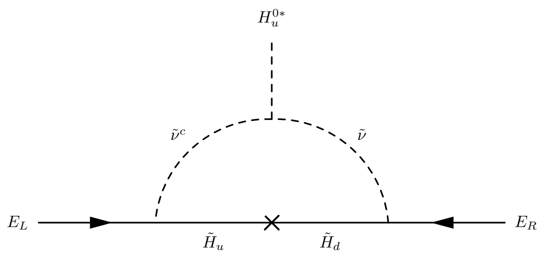

Fig. 1. – Right-handed sneutrino contribution to ϵ'_2.

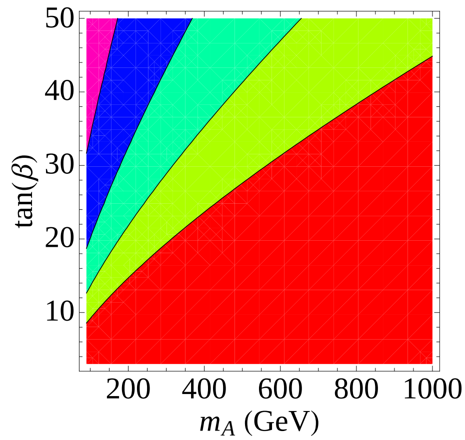

Fig. 2. – Br($\tau \to 3\mu$), the contours corresponding, from left to right, to 2.1×10^{-8}, 10^{-9}, 10^{-10}, 10^{-11}.

the new contribution due to the diagram of fig. 1 can be expressed as

$$(4) \quad \epsilon'_{2ij} = -\mu A_\nu \frac{\mu^2 m^2_{\widetilde{\nu}_i} \ln(\mu^2/m^2_{\widetilde{\nu}_i}) + m^2_{\widetilde{\nu}_i} m^2_{\widetilde{\nu}^c_j} \ln(m^2_{\widetilde{\nu}_i}/m^2_{\widetilde{\nu}^c_j}) + m^2_{\widetilde{\nu}^c_j}\mu^2 \ln(m^2_{\widetilde{\nu}^c_j}/\mu^2)}{16\pi^2(\mu^2 - m^2_{\widetilde{\nu}_i})(m^2_{\widetilde{\nu}_i} - m^2_{\widetilde{\nu}^c_j})(m^2_{\widetilde{\nu}^c_j} - \mu^2)} \, .$$

Explicit formulas for the various coefficients in 3 are given and evaluated in [2]. The main feature is that, in the SUSY inverse seesaw, this new diagram provides the dominant Higgs-mediated contribution and, together with the increase of the factor ξ, it enhances ϵ_2 by a factor of order ~ 10 compared to the standard seesaw.

3. – Results and discussion

We studied several cLFV observables dominated by the Higgs penguin diagrams and found that they would be enhanced by as much as two orders of magnitude compared to the type I SUSY seesaw. It is interesting to note that m_A and $\tan\beta$ are the most relevant parameters in the Higgs-mediated flavour violating processes. To better illustrate this, in fig. 2 we study the dependence of Br($\tau \to 3\mu$) on the aforementioned parameters. We have chosen three points (CMSSM-A and CMSSM-B correspond to the 10.2.2 and 40.1.1 benchmark points in [5], NUHM-C is an example of a non-universal scenario) that are summarized in table I and we calculated several branching ratios in table II.

One can see that from an experimental point of view, the most promising channels in the SUSY inverse seesaw are $\tau \to \mu\mu\mu$ and $\tau \to \mu\eta$ which could be tested at the next generation of B factories. It is important to stress that the numerical results summarised in table II correspond to considering *only* Higgs-mediated contributions. For large $\tan\beta$ values, Higgs penguins provide the leading contributions. However, at small $\tan\beta$, due to the sizeable contributions from photon and Z penguins, our results should be interpreted as partial contributions. Another interesting property of the Higgs-mediated processes is that the corresponding amplitude strongly depends on the chirality of the heaviest lepton, which can induce an asymmetry that potentially allows to identify if Higgs mediation is the dominant contribution to the LFV observables.

Point	$\tan\beta$	$m_{1/2}$	m_0	$m^2_{H_U}$	$m^2_{H_D}$	A_0	μ	m_A
CMSSM-A	10	550	225	$(225)^2$	$(225)^2$	0	690	782
CMSSM-B	40	500	330	$(330)^2$	$(330)^2$	-500	698	604
NUHM-C	15	550	225	$(652)^2$	$-(570)^2$	0	478	150

TABLE I. – *Benchmark points used in the numerical analysis (dimensionful parameters in GeV).*

LFV Process	Present Bound	Future Sensitivity	CMSSM-A	CMSSM-B	NUHM-C
$\tau \to \mu\mu\mu$	2.1×10^{-8}[6]	8.2×10^{-10}[7]	1.4×10^{-15}	3.9×10^{-11}	8.0×10^{-12}
$\mu \to eee$	1.0×10^{-12}[8]		6.3×10^{-22}	1.5×10^{-17}	3.7×10^{-18}
$\tau \to \mu\eta$	2.3×10^{-8}[9]	$\sim 10^{-10}$[7]	8.0×10^{-15}	3.3×10^{-10}	4.6×10^{-11}
$B^0_d \to \mu\tau$	2.2×10^{-5}[10]		2.7×10^{-15}	8.5×10^{-10}	2.7×10^{-11}
$B^0_s \to e\mu$	2.0×10^{-7}[11]	6.5×10^{-8}[12]	3.4×10^{-16}	8.9×10^{-11}	3.4×10^{-12}
$h \to \mu\tau$			1.3×10^{-8}	2.6×10^{-7}	2.3×10^{-6}

TABLE II. – *Higgs-mediated contributions to the branching ratios of several LFV processes with current experimental bounds and future sensitivities.*

4. – Conclusion

In this work, we have studied Higgs-mediated LFV processes in the framework of the SUSY inverse seesaw. We found that TeV scale RH sneutrinos enhance the Higgs-mediated contributions of several LFV processes by as much as two orders of magnitude when compared to the standard (type I) SUSY seesaw.

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